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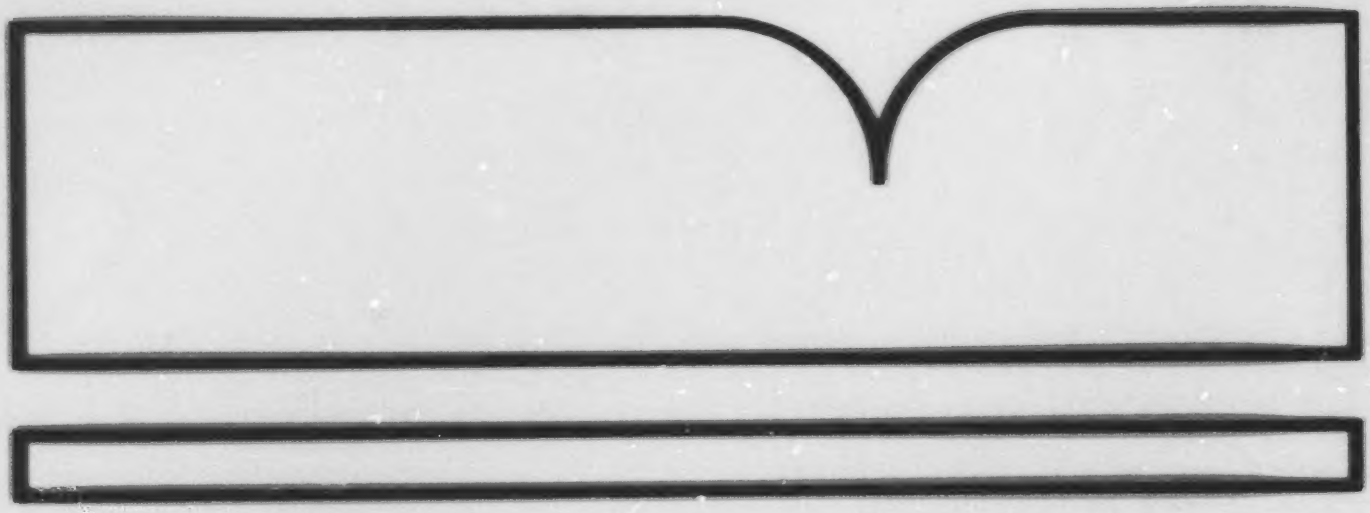

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16. ABSTRACT

Hourly precipitation data from 89 first-order National Weather Service stations in the Northeastern United States are used to define seasonal storm (wet-period) and dry-period statistics. Mean values of regional storm and dry-period duration and of precipitation rates for storms and precipitation events for each season are calculated. Frequency distributions of regional storm and dry period duration allow comparison of seasonal variations and characteristics. Such statistics serve as input parameters for studies and models developed to provide a better understanding of the deposition of acidic pollutants by precipitation.

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MESOSCALE STORM AND DRY PERIOD PARAMETERS FROM HOURLY PRECIPITATION DATA

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Abstract—Hourly precipitation data from 89 first-order National Weather Service stations in the northeastern United States are used to define seasonal storm (wet-period) and dry-period statistics. Mean values of regional storm and dry-period duration and of precipitation rates for storms and precipitation events for each season are calculated. Frequency distributions of regional storm and dry period duration allow comparison of seasonal variations and characteristics. Such statistics serve as input parameters for studies and models developed to provide a better understanding of the deposition of acidic pollutants by precipitation.

Key word index: Rainfall rates, precipitation rates, precipitation scavenging, acid rain, precipitation statistics, storm duration, hourly precipitation, mesoscale storms.

INTRODUCTION

Studies and experiments conducted at the Brookhaven National Laboratory on Long Island, New York, have shown that the deposition of hydrogen and sulfate ions is greatest in the summer and least in the winter at that site (Raynor and Hayes, 1982). Although mean monthly precipitation in the NE United States in general shows a slight spring or summer maximum (U.S. Department of Commerce, 1968), no simple relationship between precipitation amount and chemical wet deposition has yet been discovered. Precipitation rate, storm duration and seasonal variation of precipitation amount are but some of the parameters that may affect the deposition of pollutants that contribute to the acidity of lakes and streams.

An earlier estimate of seasonal variation of precipitation amount and rate was made by Thorp and Scott (1982). Average values of summer and winter regional precipitation rates and frequency distributions of storm and dry-period duration for the 19 NE states were calculated using precipitation data from 89 first-order National Weather Service (NWS) stations. The results, based on approximately 4000 station-storms each from 5 summer and 5 winter months, were not necessarily conclusive. (A station-storm is defined as any storm that produced precipitation at any of the chosen stations.)

This article reports a further analysis of precipitation patterns in the NE United States. Using a larger data base, more than 10,000 station-storms have been analyzed for each season. In addition to updating the previous study for winter and summer, the analyses have been expanded to include storm and dry-period statistics for spring and autumn.

For each season, the average regional storm and dry-period duration, average storm amount, and average storm and event precipitation rates are calculated. Results and seasonal comparisons are summarized in graphs and tables. Storm and event precipitation rates described in the earlier study were simple arithmetic averages; those values are replaced with time-weighted averages which give more importance to the rates from storms of greater duration and amount. Maximum values of hourly precipitation amount, storm amount, event precipitation rate, and duration of storm and dry period from the 1977–1980 hourly precipitation data base are also listed.

Incomplete storms and/or dry periods that occur at the beginning and end of each month were not handled well in the 1982 study. As a result, the frequency statistics were biased by excessive numbers of the shorter duration storms and dry periods. Methods used to establish wet periods (storms) and dry periods from the original hourly precipitation data, and to analyze the wet and dry periods, are described in more detail in the following sections.

DATA PROCESSING

The TD-9657 monthly data tapes as received from the National Climatic Data Center (NCDC) contain hourly precipitation amounts and 24-h daily totals for approximately 3000 stations in the U.S. Precipitation at most of these stations is measured and recorded in tenths rather than hundredths of inches. For the type of analysis described here such resolution is unfortunately much too coarse for calculating precipitation rate statistics. For that reason, only those stations having data in hundredths of inches have been used. For the NE, this limits the data set to 89 first-order NWS stations. The locations of most of the stations are shown in Fig. 1. A few stations, like Argonne National Laboratory near Chicago and Blue

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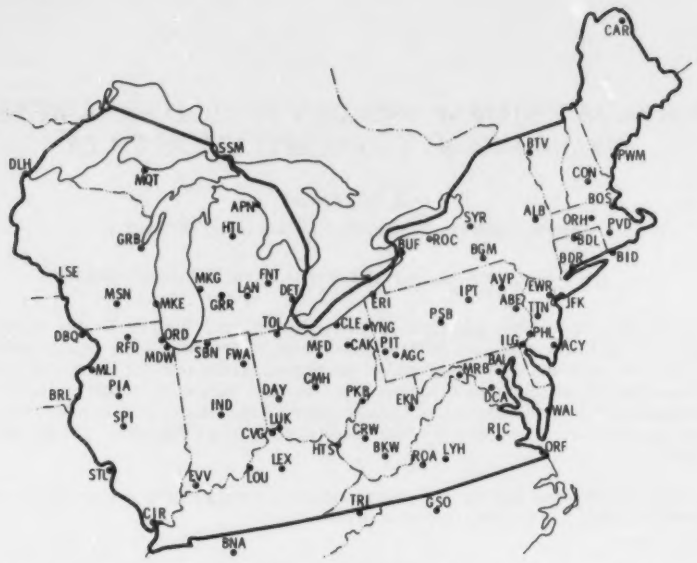

Fig. 1. First order National Weather Service stations within the northeastern United States study area.

Hill Observatory in Massachusetts, have not been given NWS call letters and are not shown.

The hourly precipitation data from the monthly tapes are processed by computer programs developed at the Pacific Northwest Laboratory. These codes, named NCCTAP and WETDRY, have been documented by Thorp and Durham (1984).

Hourly and daily precipitation data for 28 months from 1977 to 1980 were used in this study (Table 1). The seasonal data bases varied in size from 6 to 8 months. Data tapes for November and December 1977 were not in the PNL data library.

Consecutive hours of precipitation at a station are defined as a precipitation event. A storm is composed of one or more precipitation events. The events may be separated by one or a few hours in which no measurable precipitation occurred but still be considered part of the same storm. The duration of the no-precipitation periods to be allowed within a storm is one of the input values to program WETDRY. The variable assigned to this input value is called NDHR (Number of Dry Hours) and will be frequently referred to throughout this discussion. There may be several such dry periods within a storm. Event duration is independent of NDHR, but storm duration is not. Unbroken strings of dry hours longer than the chosen value of NDHR are defined as dry periods. Each dry period within the station data string continues until an hour with measurable precipitation is encountered. This occurrence signals the onset of a new storm period.

Table 1. Monthly structure of the hourly precipitation data base at PNL

Year	Season			
	Winter	Spring	Summer	Autumn
1977			A*	SO
1978	D*J*F*	MAM	J*J*A*	SON
1979	DJ*F*	MAM	J*JA	SON
1980	J			
Total months	7	6	7	8

*Denotes months used in the 1982 study.

One weakness in the calculated storm and event rates may result from having made no distinction between liquid and frozen precipitation. It is likely that the scavenging coefficients for rain and snow are not the same. The data are available for determining the type of precipitation at first order NWS stations, but merging this information with the hourly precipitation amount record was beyond the budgetary and time limitations of this project.

One problem in the analysis is the treatment of wet or dry periods that overlap the beginning or ending of a month or season. In the 1982 study these beginning and ending periods were treated as complete storms or dry periods. This caused the number of longer duration storms and dry periods to be underestimated, and erroneously increased the frequency of shorter wet and dry periods. The current analysis scheme rejects only those incomplete periods at each station that begin and end a season. The month-end and -beginning periods within the season are treated correctly as continuing periods, substantially increasing the number of storms and dry periods available for analysis.

The value given to NDHR is generally a function of

the seasonal precipitation characteristics of the region being studied. For example, convective storms, most likely to occur in the late spring, summer and early autumn in most of the U.S., are showery in nature and usually last only a few hours. For those storms, then, a period of no rain or of rain less than 0.01 in. (2.5 mm) occurring within the storm should probably be limited to 1 or 2 h. In winter, however, precipitating weather disturbances are more likely to be associated with the larger scale traveling pressure depressions, frontal systems, or troughs that may be coherent over several states. Because of their size, such storms are likely to produce several hours of precipitation at stations over which they pass. But the precipitation in such large systems may be organized in bands that cause changes of intensity or periods in which no precipitation reaches the ground. Nonprecipitating periods of 1 or more hours in such storms are not uncommon. In the NE in winter a value for NDHR of 3 h would not be unreasonable.

DATA ANALYSIS

The purpose of the analysis is to provide a set of average storm and dry-period characteristics that can be used as input to models and studies of wet deposition of airborne pollutants.

The hourly precipitation data were analyzed by season, and storms occurring within the 19-state NE region were arranged in a frequency distribution with a class interval of 1 h. Since dry periods may be several hundred hours in duration, a class interval of 20 h was chosen for the dry-period frequency distribution to prevent the dry-period tables from being excessively long.

Among the parameters calculated for each duration class interval are the following:

1. The number of storms (at all stations).
2. Cumulative percent of the total number of storms (from all stations).
3. The total regional precipitation from storms at all stations.
4. The average precipitation per storm.
5. The average storm precipitation rate.
6. The number of precipitation events.
7. The average number of events per storm.
8. The average duration of precipitation events.
9. The average event precipitation rate.
10. The fraction of the total regional precipitation.
11. The three-point smoothed fraction of the total regional precipitation.
12. The cumulative fraction of total regional precipitation.

The last three items may need brief explanations. The fraction of the regional precipitation is that fraction of the seasonal total regional precipitation (from the 89 chosen stations) that is attributed to all the storms of each hourly duration class. The smoothed fraction is a three-point smoothed average of item 10. The cumulative fraction of the total regional precipitation is the accumulating sum of item 10.

For the dry-period frequency analysis, two parameters are calculated for each frequency class:

1. Number of dry periods.
2. Percent frequency of the total number of dry periods.

In addition to the frequency distribution statistics above, the following seasonal grand (all-storm) averages are calculated:

1. Grand average storm precipitation rate.
2. Grand average storm duration.
3. Grand average event precipitation rate.
4. Grand average dry period duration.

The average event precipitation rate is calculated using:

$$r_e = \frac{\sum_{i=1}^{m} r_i \Delta t_i}{\sum_{i=1}^{m} \Delta t_i}$$

where m = the number of events
Δt_i = the duration of the ith event
r_i = the rate for the ith event, $\frac{P_i}{\Delta t_i}$
P_i = the precipitation amount for the event.

The equation reduces to total precipitation/sum of all event durations. In the earlier (1982) article, the event rate was determined by the sum of all event rates/number of events. That procedure gave equal importance to event rates from both short and long duration events. Depending on whether NDHR is zero or greater than zero, the average storm precipitation rate is always equal to or less than the average event precipitation rate. That is, the average storm precipitation rate decreases as NDHR is increased.

The average storm precipitation rate is calculated similarly; however in that case Δt_i represents the storm durations that include dry hours when the variable NDHR has been set to a value greater than zero.

RESULTS

Storm and dry-period sums and averages are displayed by season in Table 2. Multiple columns for each season show the variation in certain statistics as the length of the no-rain periods allowed within a storm, NDHR, is increased from 0 to 2 h (and to 3 h in winter).

The extremes encountered within the data base for each season are shown in the lower section of Table 2. Though the data bases are too short to be used in establishing climatological extremes, it is of interest that some stations or subregions in the study area experienced either record, or near-record, droughts or excessive precipitation amounts during the period of

Table 2. Seasonal sums, averages, and extremes of storm and dry period parameters for the northeast United States (1977–1980)

Season	Spring		Summer		Autumn		Winter		
Consecutive dry hours within storm (NDHR)	0	2	0	2	0	2	0	2	3
SUMS									
Months of data analyzed	6	6	7	7	8	8	7	7	7
Number of stations in seasonal analysis	86	86	88	88	88	88	87	87	87
Station-hours analyzed	366710	366579	425082	425006	468725	468642	406837	406566	406457
Station-hours with precipitation	35287	35180	25718	25656	36694	36627	48317	48105	48031
Number of station-months	518	518	618	618	705	705	609	609	609
Number of station-storms	10562	7304	10196	7912	11040	7827	12480	7906	7064
Number of station-events	10562	10519	10196	10170	11040	11010	12480	12408	12380
Number of station-dry periods	10416	7182	9958	7688	10809	7614	12269	7721	6891
AVERAGES									
Average number of storms per station per month	20	14	16	13	16	11	20	13	12
Percent of station-hours with precipitation	10	10	6	6	8	8	12	12	12
Average monthly regional precipitation per station (mm)	89.9	89.7	103.5	103.4	83.2	83.1	81.5	81.3	81.3
Average storm precipitation amount (mm)	4.41	6.36	6.28	8.08	5.31	7.48	3.98	6.27	7.01
Average storm duration (h)	3.3	5.4	2.5	3.6	3.3	5.2	3.9	6.9	9.0
Average storm precipitation rate (mm/h)	1.32	1.18	2.49	2.12	1.60	1.43	1.03	0.91	0.87
Average number of events per storm	1.0	1.4	1.0	1.3	1.0	1.4	1.0	1.6	1.8
Average event duration (h)	3.3	3.3	2.5	2.5	3.3	3.3	3.9	3.9	3.9
Average event precipitation rate (mm/h)	1.32	1.32	2.49	2.49	1.60	1.60	1.03	1.03	1.03
Average dry period duration (h)	31.8	45.5	40.1	51.5	40.0	56.2	29.2	45.6	50.8
Average number of dry periods per station per month	20	14	16	12	15	11	20	13	11
EXTREMES									
Maximum hourly precipitation amount (mm)	58.4	58.4	75.9	75.9	71.9	71.9	25.4	25.4	25.4
Maximum storm precipitation amount (mm)	164.6	168.6	184.7	186.7	167.6	169.7	109.2	161.5	161.5
Maximum event precipitation rate (mm/h)	21.8	21.8	46.7	46.7	39.4	39.4	9.9	9.9	9.9
Maximum storm duration (h)	47	76	30	44	38	49	39	71	71
Maximum dry period duration (h)	440	440	531	531	782	782	523	523	523

study. For example, September 1979 was the driest month in more than 100 years of record for eastern Missouri to lower Michigan (Ludlum, 1979a). January of the same year saw near-record amounts of precipitation in areas of Maine and Massachusetts (Ludlum, 1979b).

Before comparing the seasonal averages in Table 2, the reader is reminded that the data sets used in these analyses varied from 6 months for spring to 8 months for autumn (Table 1). The 1977–1980 precipitation data show that summer storms, on the average, had the shortest duration and the greatest precipitation amount on a per-storm basis; conversely, winter storms had the longest average duration, but produced slightly less precipitation than other seasons. Both storm and event average precipitation rates were greatest in summer and least in winter. Spring and autumn rates fell between, with autumn rates being slightly greater than spring rates, though the average storm duration was the same for those seasons.

Other seasonal comparisons of storms (when NDHR = 2 h) are shown in Table 3. Winter statistics when NDHR is increased to 5 h are also shown to illustrate the effect of allowing longer periods of no rain to occur within the storms.

The Table 3 statistics for autumn and spring are similar and fall between the values calculated for winter and summer. The average event precipitation rate (2.9 mm h^{-1}) for the class of 3-h summer storms that produced the greatest fraction of regional precipitation was more than twice the rates for the primary contributing winter and spring storms, and substantially greater than the rate for similar storms of autumn.

Plots comparing storm duration vs cumulative percent of storm duration frequency, cumulative fraction of total precipitation and fraction of total seasonal precipitation are shown for each of the four seasons in Fig. 2. The two cumulative curves for each season again point up the similarity between spring and autumn frequency of storm duration and fraction of total precipitation, and the uniqueness of those same storm characteristics for winter and summer.

In Fig. 3, the variation of the fraction of the total seasonal precipitation vs storm duration is plotted as a function of NDHR. The plots resulted from setting NDHR to 0, 1 and 3 h for spring, summer and autumn storms, and 1, 3 and 5 h for winter storms. Note that as NDHR is increased, the seasonal characteristics of the cumulative and fractional curves are preserved, yet the differences among seasons are still apparent. This is especially noticeable in the diagram for winter.

The first nine classes (to 180 h) of the dry-period duration frequency distribution are shown in Fig. 4. Ninety-five percent of all dry periods fell within these nine classes. More than 40% of the dry periods in all seasons were in the 0–20-h duration category. The seasonal frequencies of dry periods that were longer than 20 h were within a few percent of each other. From Table 2 the mean dry interval between storms was about 45 h in winter and spring, 51 h in summer, and greatest of all in autumn at 56 h (all when NDHR = 2 h). The longest dry period occurring in this data set was 782 h at St. Louis, Missouri, in September 1979. The autumn analysis showed five other occurrences of dry periods greater than 700 h. Since September 1979 was the driest month in more than 100 years of record for the area from eastern Missouri to lower Michigan, the St. Louis value probably is not often exceeded in the entire Northeast. Dry periods of 400–540 h occurred at a few stations in each season, even in winter. However, of more than 31,000 dry periods that were analyzed, less than 5% were longer than 200 h in duration.

Table 3. Seasonal comparison of storm statistics

Season =	Winter		Spring	Summer	Autumn
NDHR =	2 H	5 H	2 H	2 H	2 H
Two thirds of the storms were shorter than:	7 h	11 h	5 h	3 h	5 h
Two thirds of the regional precipitation came from storms shorter than:	21 h	27 h	14 h	7 h	13 h
90% of the storms were shorter than:	16 h	25 h	12 h	8 h	12 h
90% of the regional precipitation came from storms shorter than:	31 h	39 h	25 h	14 h	21 h
The storm class duration that produced the greatest fraction of regional precipitation:	12 h	25 h	6 h	3 h	5 h
Average number of events in storms of above class:	2.0	3.6	1.4	1.1	1.4
Average event precipitation rate in storms of above class (mm $h)^{-1}$	1.1	1.2	1.3	2.9	1.7

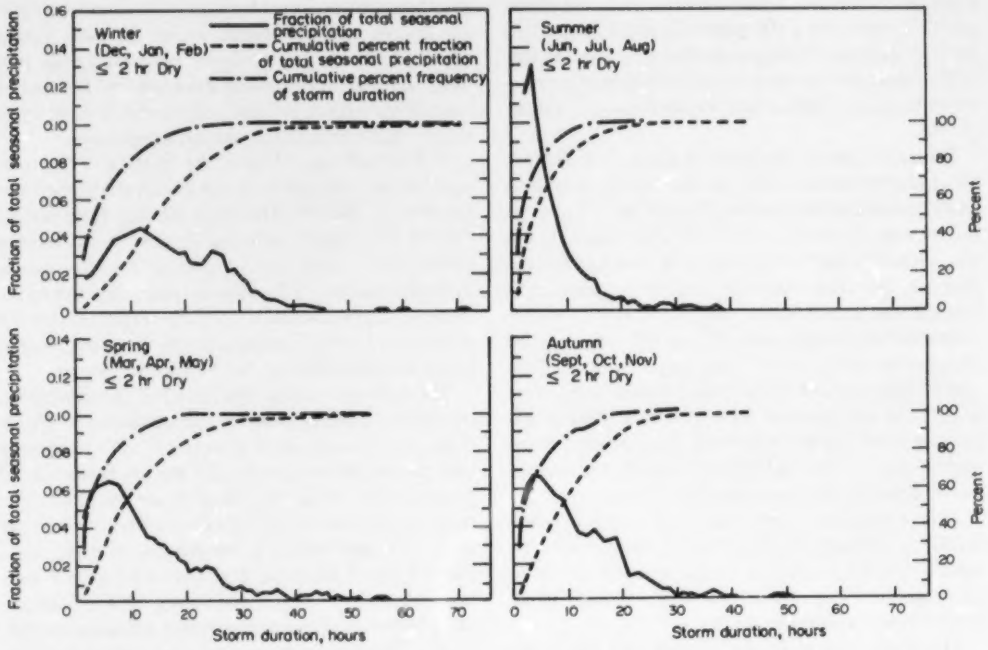

Fig. 2. Fraction of total seasonal precipitation, cumulative percent fraction of total seasonal precipitation and cumulative percent frequency of storm duration for the four seasons (NDHR = 2).

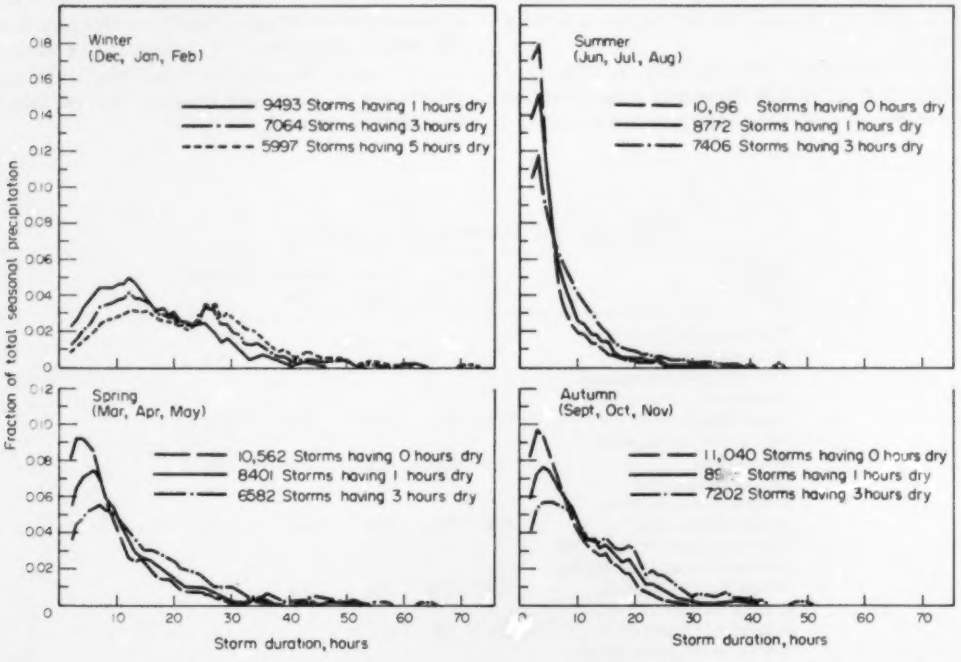
Winter
(Dec, Jan, Feb)
9493 Storms having 1 hours dry
7064 Storms having 3 hours dry
5997 Storms having 5 hours dry
Summer
(Jun, Jul, Aug)
10,196 Storms having 0 hours dry
8772 Storms having 1 hours dry
7406 Storms having 3 hours dry
Spring
(Mar, Apr, May)
10,562 Storms having 0 hours dry
8401 Storms having 1 hours dry
6582 Storms having 3 hours dry
Autumn
(Sept, Oct, Nov)
11,040 Storms having 0 hours dry
Storms having 1 hours dry
7202 Storms having 3hours dry
Fraction of total seasonal precipitation
Storm duration, hours

Fig. 3. Seasonal changes in the fraction of total seasonal precipitation as a function of the duration of no-rain periods included within storms.

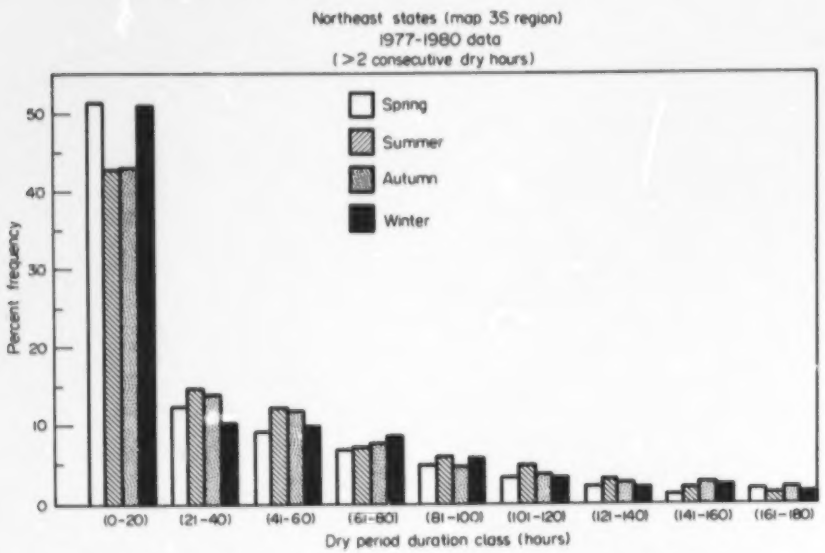

Fig. 4. Frequency distribution of dry period duration for the first nine 20-h classes.

CONCLUSIONS

The analyses for the NE states show that storms covering a wide range of duration classes contribute significantly to winter precipitation, while in other seasons storms of relatively short duration dominate. The largest contributors to regional winter precipitation were the storms of 12-h and 25-h duration. In summer, the major regional precipitation came from storms of only 3-h duration, and storms longer than 15 h were so infrequent that their contribution to the whole was minor. Storms of about 5- to 6-h duration were the primary precipitation contributors for the spring and autumn seasons. Total regional precipitation was greatest in summer, followed in decreasing order by that of spring, autumn and winter. Precipitation rates in both storms and events were greatest in summer, less for autumn and spring, and least for winter. The type of winter precipitation (liquid or frozen) has not been considered in the analysis.

The average dry-period duration (when NDHR = 2 h) was 56.2 h for autumn, 51.5 h for summer, and 45.5 h for winter and spring.

One of the difficulties in calculating storm statistics over a large area results from regional variation of the climatic normals that usually occur. For example, when the 30-year precipitation normals for the study area are examined, subregions of normal winter precipitation varying from < 10 to > 30 cm become apparent. Similar variations are likely to occur for the other seasons. Further study is needed to establish storm- and dry-period characteristics for climatologically similar subregions. To provide reliable averages and frequency distributions in such a study, a data base larger than that used for this study would be required. This type of research could be expanded to include precipitation data from other countries or continents.

The present study has shown that seasonal differences in storm and dry period characteristics do exist for the NE. Eulerian models and studies of wet deposition that make use of average storm parameters must take these seasonal differences into account.

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REFERENCES

Ludlum D. M. (1979a) Weatherwatch. *Weatherwise* **32**, 258–264.

Ludlum D. M. (1979b) Weatherwatch. *Weatherwise* **32**, 86–92.

Raynor G. S. and Hayes J. V. (1982) Variation in chemical wet deposition with meteorological conditions. *Atmospheric Environment* **16**, 1647–1656.

Thorp J. M. and Durham J. L. (1984) *Mesoscale storm and dry period parameters from hourly precipitation data: program documentation*. PNL-5242, Pacific Northwest Laboratory, Richland, Washington.

Thorp J. M. and Scott B. C. (1982) Preliminary calculations of average storm duration and seasonal precipitation rates for the northeast sector of the United States. *Atmospheric Environment* **16**, 1763–1774.

U. S. Department of Commerce (1968) *Climatic Atlas of the United States*, pp. 1–80, U. S. Government Printing Office, Washington, DC.